BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Comments on LM Landing at Nine Potential Science Sites - Case 340

DATE: April 24, 1968

FROM: I. Silberstein

ABSTRACT

The Group for Lunar Exploration Planning (GLEP) Site Selection Working Group recently selected a list of nine potential landing sites for science oriented missions. All of these sites were chosen for their scientific interest rather than on the basis of operational considerations. Some of the operational difficulties involved with the landing maneuver to each of those sites are identified.

The conclusion is that the demands on navigational accuracy and the rough approach terrain to the sites will dictate a change in the landing procedure.

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MEMORANDUM FOR FILE

INTRODUCTION

At a working group meeting of the Group for Lunar Exploration Planning (GLEP), in December 1967, nine sites of scientific interest were chosen as potential sites for manned lunar exploration. Sites were selected that would offer maximum scientific return from missions during the period following the early Apollo landings. However, little consideration was given to operational factors such as navigation and trajectory interaction with the terrain. These factors will be discussed with reference to each of the chosen sites.

INFLUENCE OF SITE LATITUDE

The first major difference between the sites for the early Apollo missions and the science sites is that the restriction on the latitude has been relaxed. The range of latitudes of the nine science sites is between 26° N and 41° S. An immediate consequence is that free return trajectories will not be possible in most cases.

The orbital inclination of the Command and Service Module (CSM) is a function of the latitude of the site and the surface stay-time of the Lunar Module (LM). For simplicity, we assume that the LM will not perform a plane change during landing or ascent. An approximate calculation of the azimuth of approach of the LM to the landing site can then be carried out (Appendix). Since small deviations from the calculated azimuth of approach will result in a large increase in the ΔV required for an abort maneuver, the direction of the LM approach is restricted. The librations of the moon allow some freedom in the choice of approach ray at the cost of restricting the mission to one or two months per year.

SITE AND APPROACH RAY INFLUENCE

In contrast with the early Apollo missions, the primary factor in the choice of the science sites has not been their compatibility with the LM guidance system. The desire to insure the safety of the LM crew under conditions which are not completely defined, led to the choice of areas which are as flat and hazard free as possible for early Apollo sites. Landings may be performed almost anywhere within these areas. The terrain along the approach ray to each site is flat and free of large craters or hills.

The major objective of each mission to a science site is the exploration of a number of specific features in the neighborhood of the landing point. But the range of the astronauts is limited. Assuming 5 km for their maximum range with a mobility system, the landing point must be within that distance from every feature of interest. Only a small fraction of the area near these features may be suitable for landing. Since such areas are much smaller than the 3σ error ellipse of the navigation system, the landing is essentially to a point. Two requirements must be met. First, the landing point must qualify for a safe landing, and second, the capability to land at a predetermined point must exist.[5] Thus, the landing point at each site is dictated by the location of the features of interest and by the range of the astronauts. But once the landing point has been decided upon the approach ray is determined to within a few degrees.

Topographic features along the approach path strongly influence the trajectory of the LM. The vehicle altitude, as well as other data, is needed by the guidance system to deliver the LM to a predetermined point called high gate. The guidance system computes the altitude independently, based on integration of the accele ation data from the IMU. But, as a check, it updates the computed value periodically with a direct measurement of the local altitude made by the landing radar. Based on these and other data the guidance system commands a thrust and pitch angle which would eventually bring the LM to high gate. If the IMU based and the radar measured altitudes do not agree, however, a correction is made on the former to bring it nearer to the latter. As a result, the next pitch and thrust command will be changed also. As the LM gets nearer to high gate the necessary correction must be made in a shorter time. The corrections for a given altitude error become more violent as the LM approaches high gate.

This procedure is well suited for flat approach terrain, as is the case with the Apollo sites. But that is not the case with the science sites, and the pitch variations induced by the terrain elevation differences may cause radar drop out, loss of visibility, or possibly, crashing.

Thus, in order to land at some of the scientific sites, a change in the landing procedure may be necessary.[5]

LIST OF POTENTIAL SCIENCE SITES

The nine sites selected for potential surface missions are:

1. Censorinus; 0° 23' S, 32° 32' E
2. Crater chain south of Abulfeda; 14° 57' S, 14° 18' E
3. Littrow Rilles area; 31° 44' N, 29° 02' E
4. Hadley Rille; 24° 42' N, 2° 57' E
5. Hyginus Rille; 8° 0' N, 6° 10' E
6. Tycho ejecta blanket; 40° 54' S, 11° 21' E
7. Copernicus
   (a) Central peaks; 9° 43' N, 20° 0' W
   (b) Ledge on northern wall; 10° 51' N, 20° 9' W
8. Schröter's Valley
   (a) Southern site; 24° 20' N, 49° 29' W
   (b) Northeastern site; 25° 12' N, 49° 16' W
   (c) Northwestern site; 25° 28' N, 49° 58' W
9. Marius Hills
   (a) 14° 35' N, 56° 37' W
   (b) 14° 00' N, 55° 33' W
   (c) 13° 24' N, 55° 30' W

References (1) and (3) describe the features of interest at each site and the scientific objective of each mission. Based on these features of interest, and subject to mobility restrictions, Reference (4) gives justification to the choice of each landing site.

APPROACH RAYS

Actual elevation profiles along each approach ray are not available at present. Thus a photograph of the probable approach path (see Appendix) to each site is given (Figures 1 through 10).

Each photograph includes the trace of the 3σ ellipse, a 10 km scale, and the sun angle. The major obstacles are identified.

CONCLUSIONS

The difficulties imposed by the rough approach terrain to most sites will dictate some changes in the landing procedure. The most important objective of the new landing method must be the independence of the trajectory from the terrain below. The secondary objective is to improve the navigational accuracy.

Some unpublished work done at Bellcomm suggests that the position errors at the landing point due to orbital uncertainty could be reduced. While this has little bearing on the Apollo mission, subsequent missions may benefit by further study of that problem.

The Lunar Orbiter V photography is insufficient in at least two cases. Abulfeda and Censorinus are covered by a single frame and, thus, height information is not available. In other cases (Copernicus and Schröter's Valley) photography of the approach path does not extend as far as desirable east of the site.

2015-IS-acm

I. Silberstein

Attachments
- Acknowledgment
- References
- Figures 1 to 10
- Appendix
- Tables 1 and 2
- Figures A1 and A2

ACKNOWLEDGMENT

The author is indebted to Mr. F. El-Baz for his help in preparing Figures 1 through 10.

REFERENCES

1. Minutes of the GLEP Site Selection Working Group, December 8 and 9, 1967.

2. Lunar AAP Mission Profiles, D. R. Anselmo and W. D. Kinney, TM 67-2011-1, September 29, 1967.

3. A Lunar Exploration Program, N. W. Hinners, D. B. James, F. N. Schmidt, TM 68-1012-1, January 5, 1968.

4. The Nine Lunar Landing Mission Sites Recommended by the Group for Lunar Exploration Planning, F. El-Baz, Technical Report (to be published).

5. LM Landing Using Steep Descent Trajectory, I. Silberstein, TM-68-2015-1, April 3, 1968.

L.O.V M.R 63.*

CENSORINUS

(1) LANDING POINT.

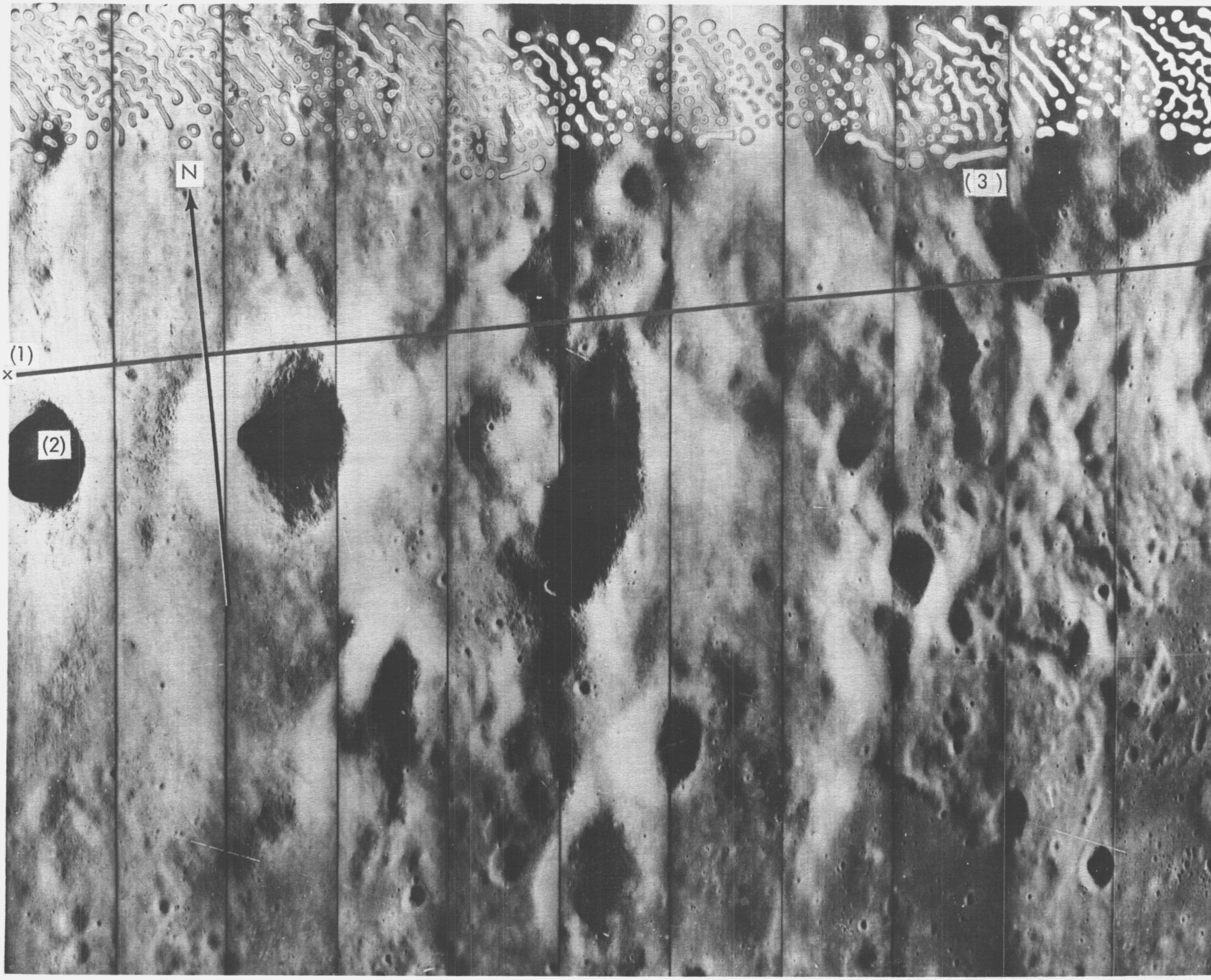
(2) CENSORINUS. (3.5 km diameter)**

(3) MASKELYNE A.

FIGURE 1

* Lunar Orbiter V, Medium Resolution, Frame Number 63.

** This is an oblique photograph. The scale is variable, and so is the sun angle.



N
(3)
(1)
x
(2)

L.O.V M.R 84.

ABULFEDA

(1) LANDING POINT.

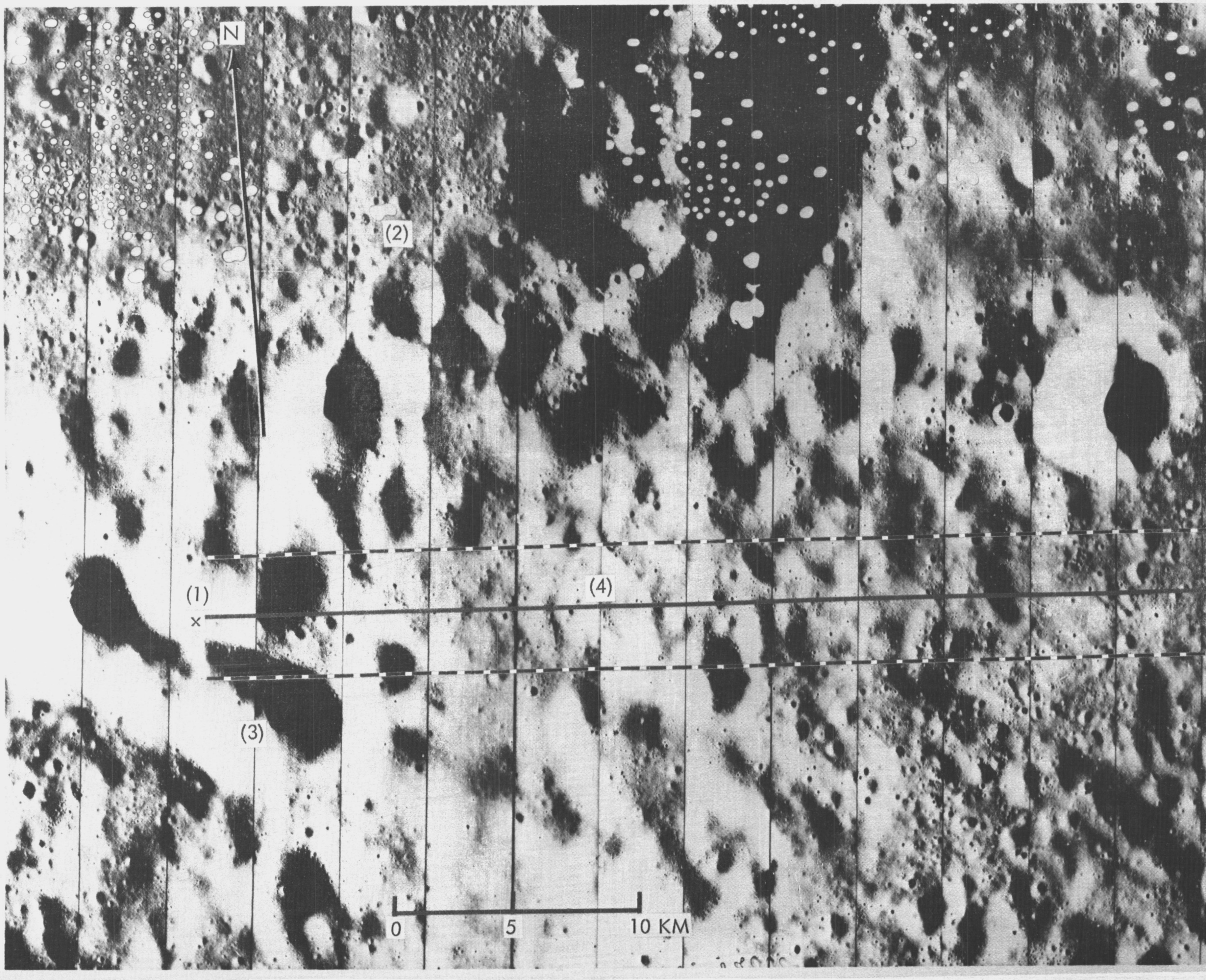
(2) ABULFEDA CRATER.

(3) CRATER CHAIN.

(4) GENERAL SLOPE UP TO LANDING SITE.

SUN ANGLE ≈ 17°

FIGURE 2


N
(2)
(1)
×
(4)
(3)
0
5
10 KM

L.O.V M.R 66.

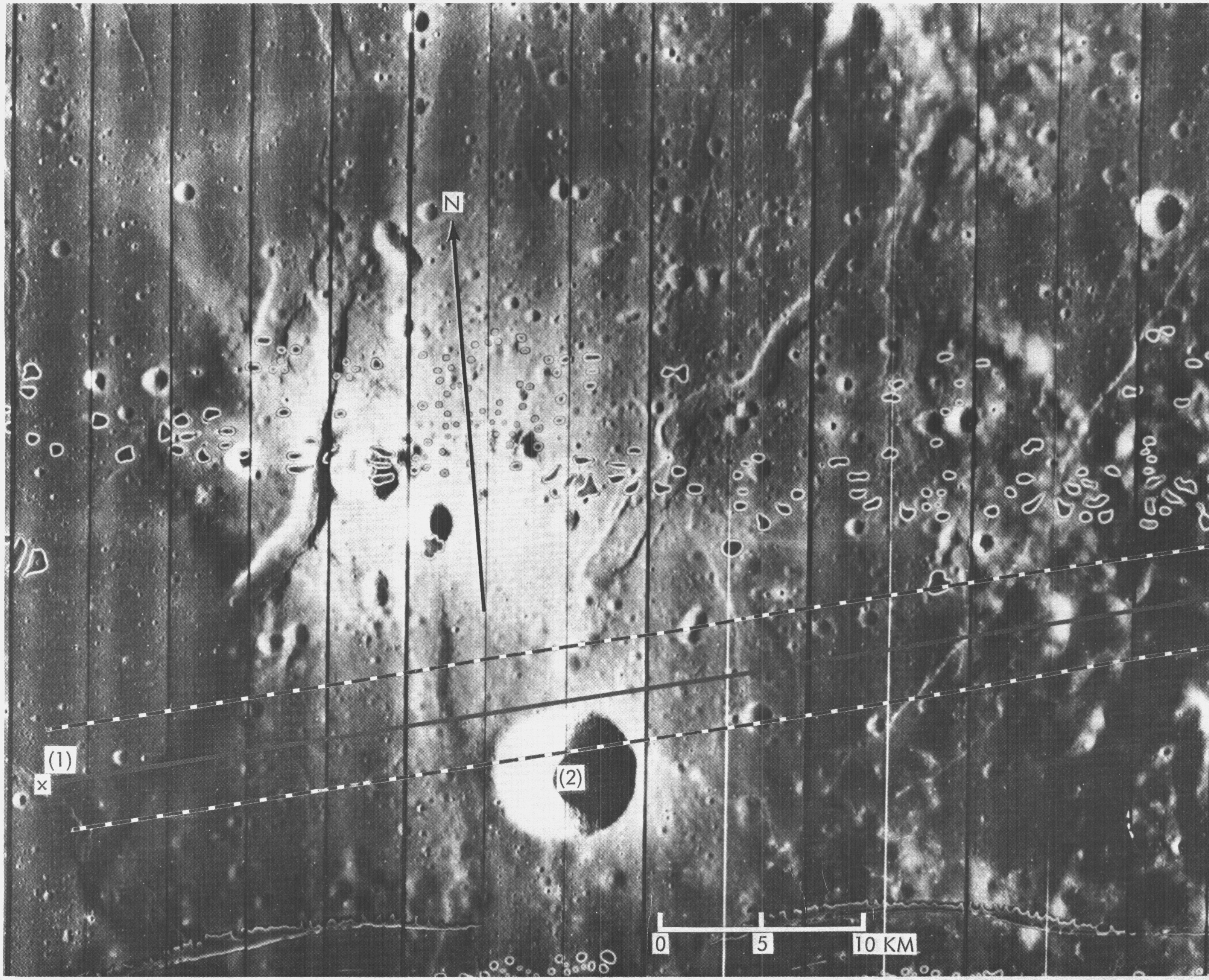
LITTROW RILLE AREA

(1) LANDING POINT.

(2) LITTROW B CRATER. (depth ≈ 1 km)

SUN ANGLE ≈ 21°

FIGURE 3



N
(1)
x
(2)
0
5
10 KM

L.O.V M.R 105.

HADLEY RILLE

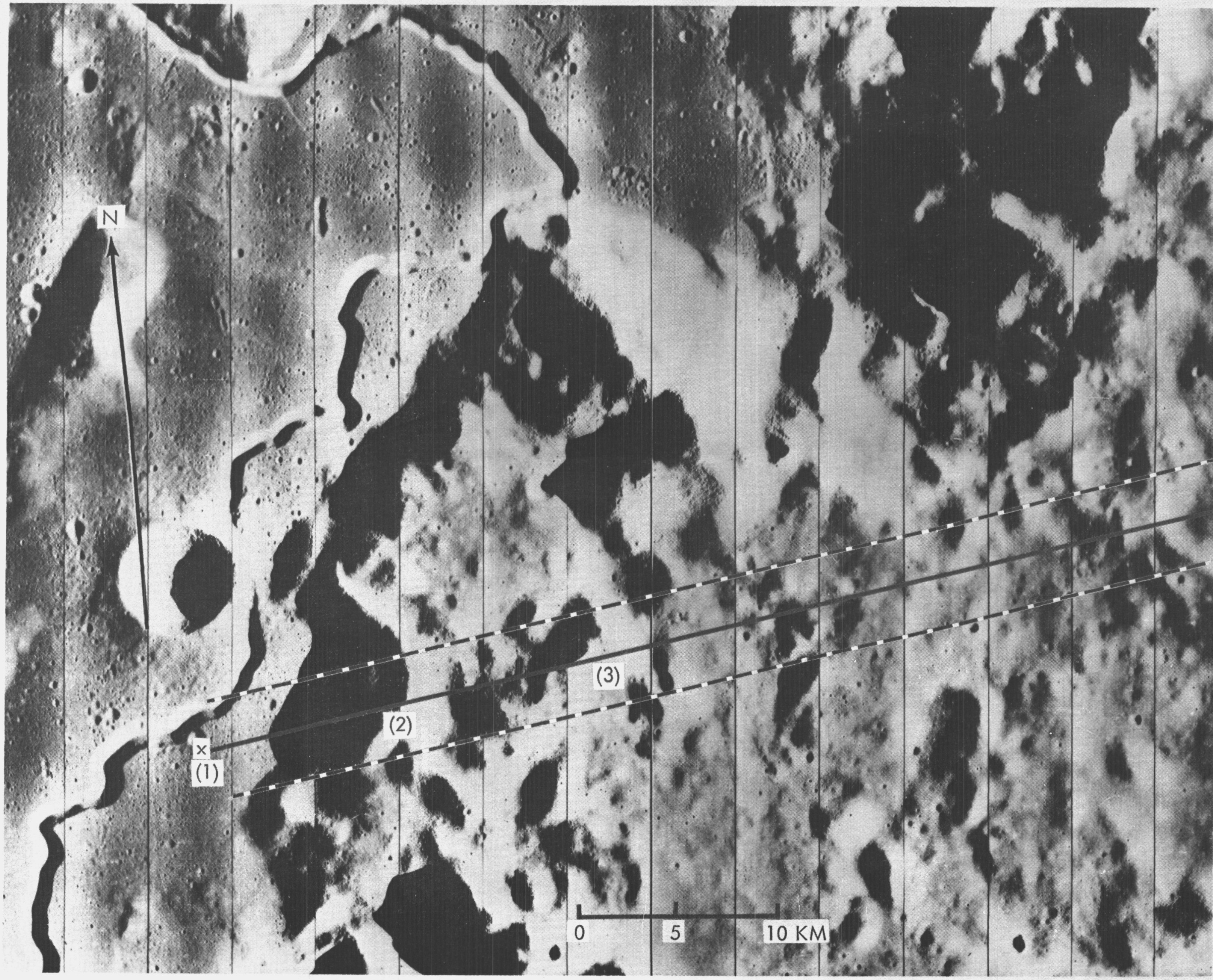
(1) LANDING POINT.

(2) APENNINE RIDGE, WESTERN SLOPE. (height ≈ 1200 meters)

(3) APENNINE RIDGE.

SUN ANGLE ≈ 20°

FIGURE 4



N
x
(1)
(2)
(3)
0
5
10 KM

L.O.V M.R 96.

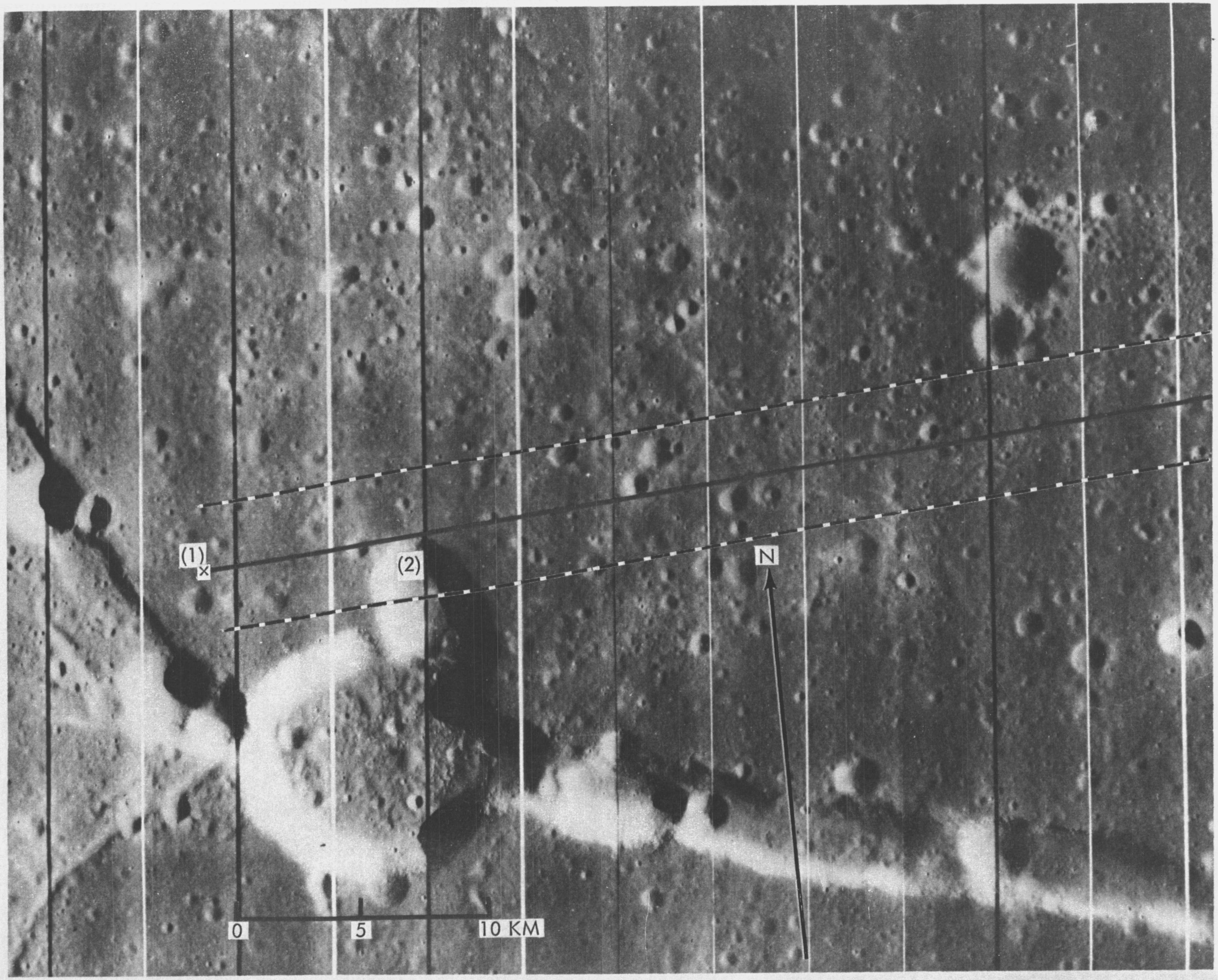
HYGINUS RILLE

(1) LANDING POINT.

(2) HYGINUS CRATER.
(depth ≈ 900 meters)

SUN ANGLE ≈ 20°

FIGURE 5



(1)
x
(2)
N
0
5
10 KM

L.O.V M.R 126.

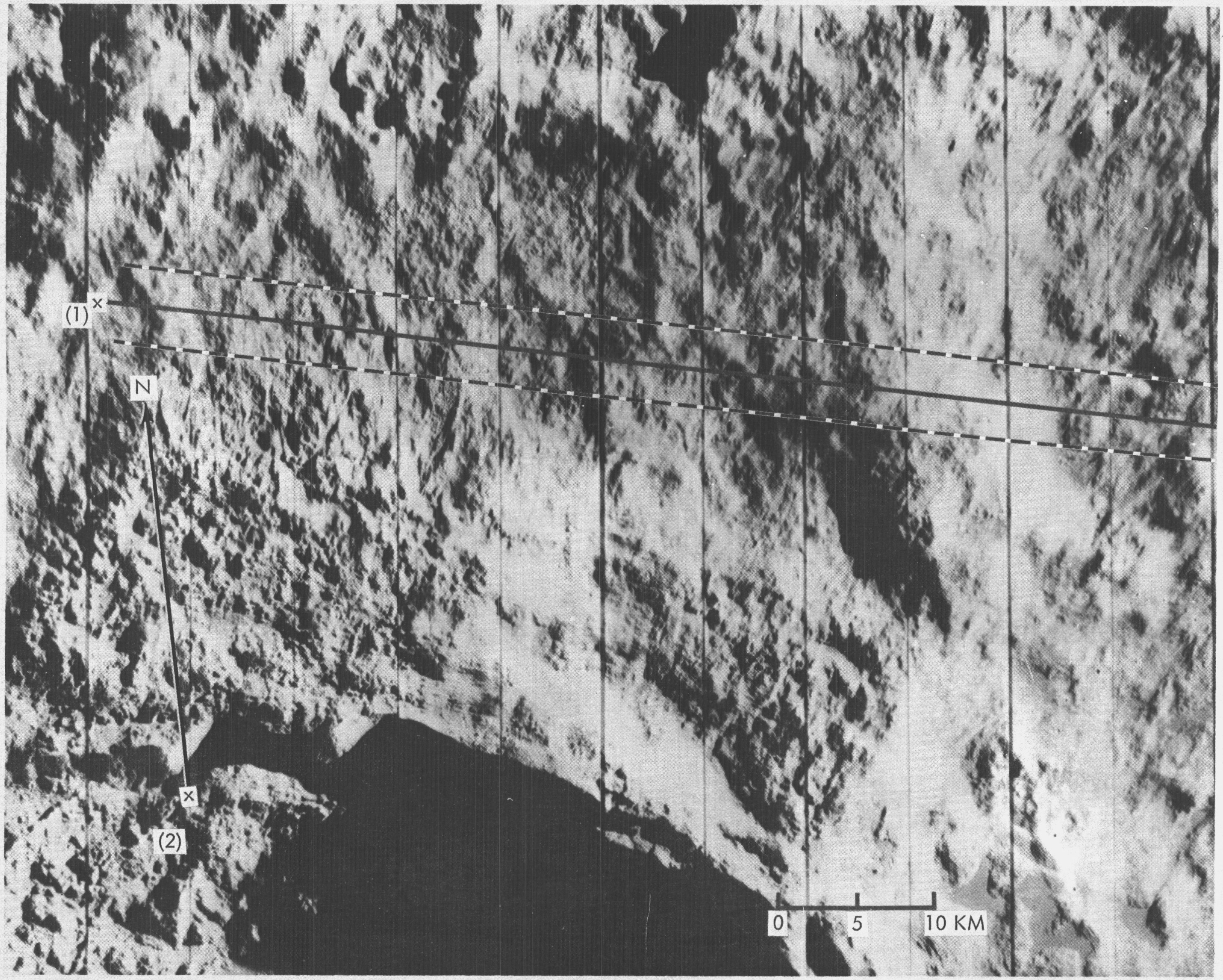
TYCHO

(1) LANDING SITE.

(2) TYCHO CRATER.

SUN ANGLE ≈ 10°

FIGURE 6



(1)
N
(2)
0
5
10 KM

L.O.V M.R 155.

CENTRAL PEAKS OF COPERNICUS

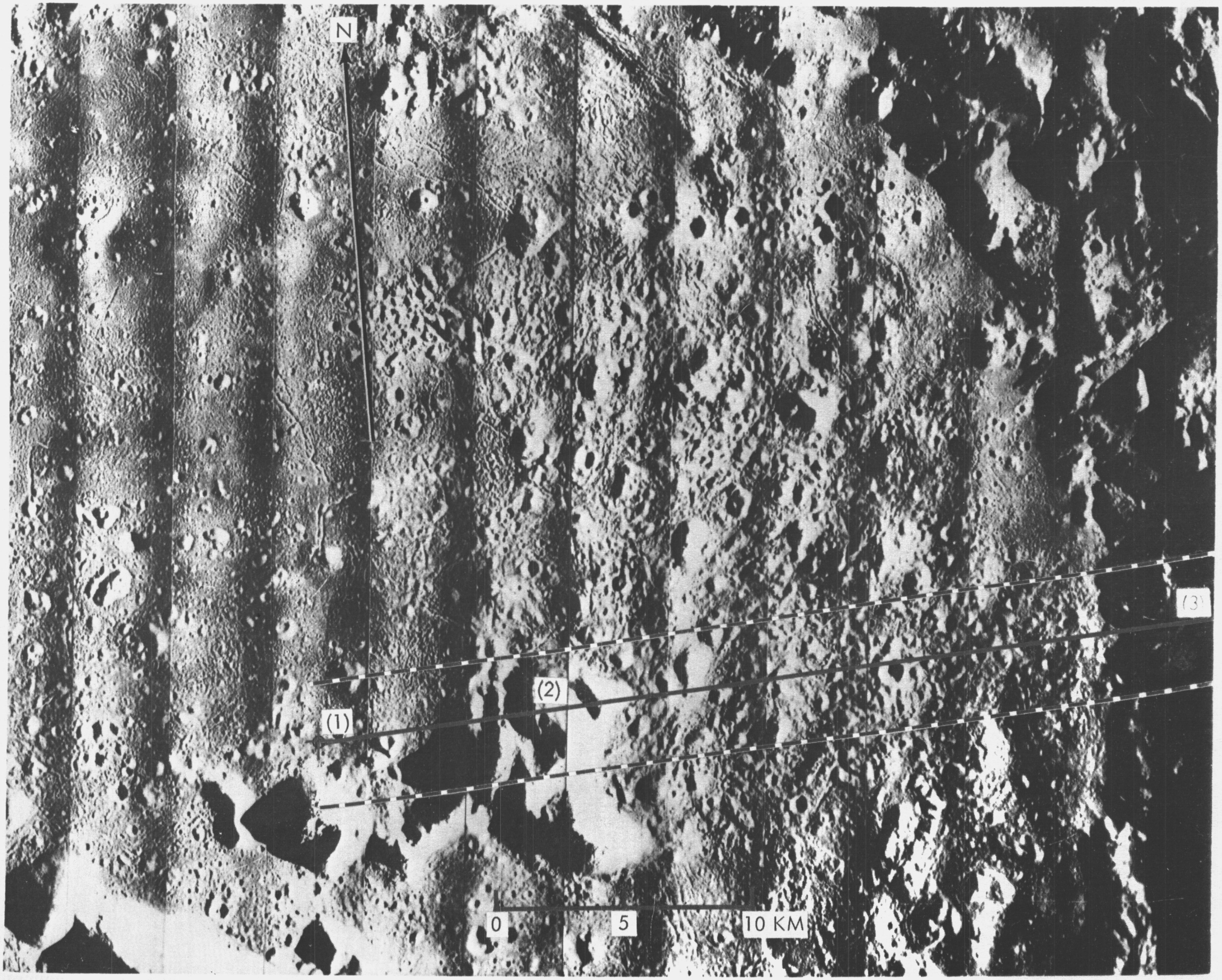
(1) LANDING POINT.

(2) CENTRAL PEAKS.
(height $\approx$ 2.5 km)

(3) EAST WALL OF CRATER.

SUN ANGLE $\approx 18°$

FIGURE 7


N
(1)
(2)
(3)
0
5
10 KM

L.O.V M.R 155.

COPERNICUS CRATER

(1) LANDING POINT.

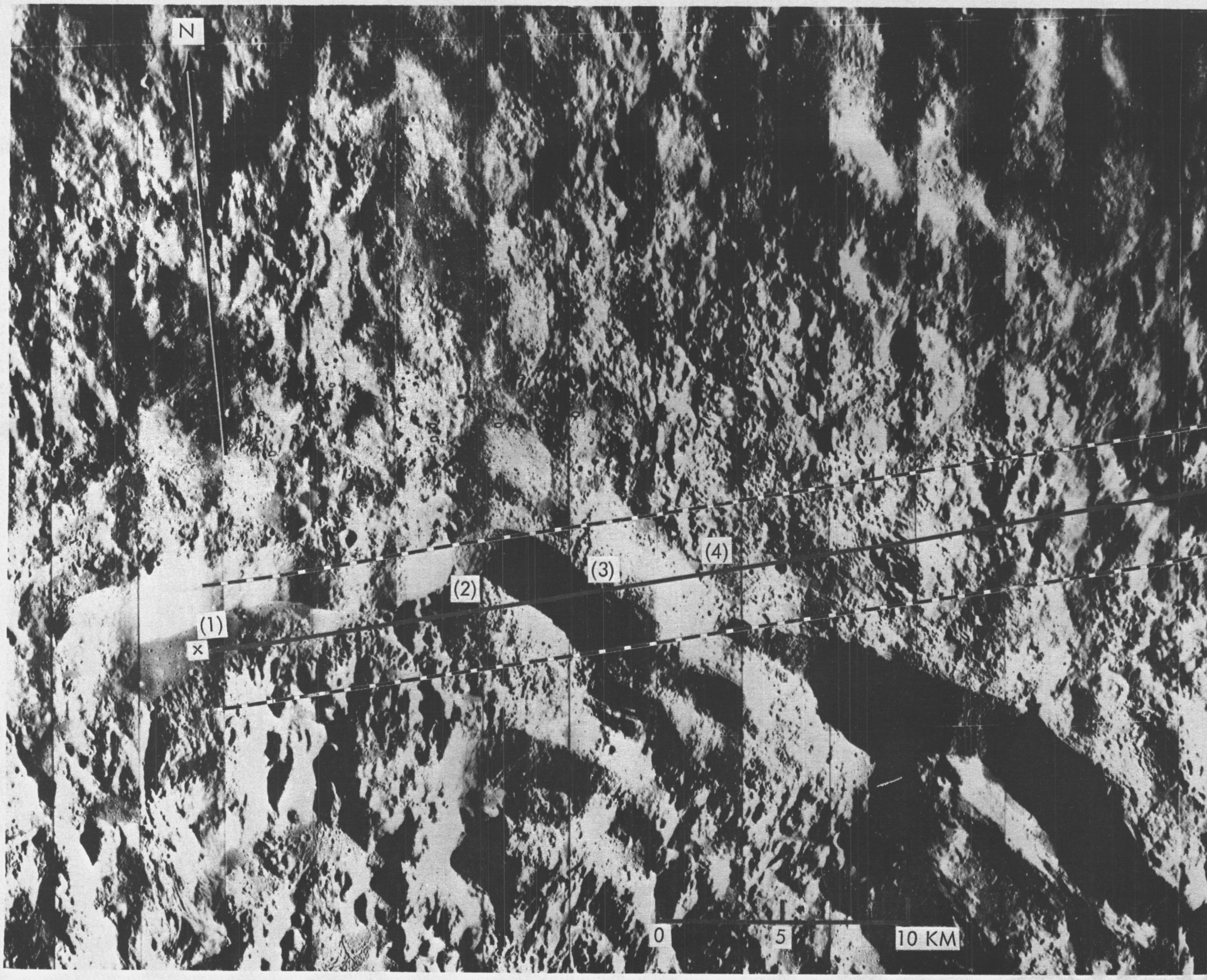
(2) SLUMP BLOCK.

(3) CRATER WALL. (1000 meters)

(4) SLOPE UP TO CRATER WALL.

SUN ANGLE ≈ 18°

FIGURE 8



N
(1)
x
(2)
(3)
(4)
0
5
10 KM

L.O.V M.R 214.

SCHRÖTER'S VALLEY

(1) a;b;c LANDING SITES IN ORDER OF PREFERENCE.

(2) SCHRÖTER'S VALLEY ≈ 800 M DEEP.

(3) CRATER ≈ 800 M DEEP.

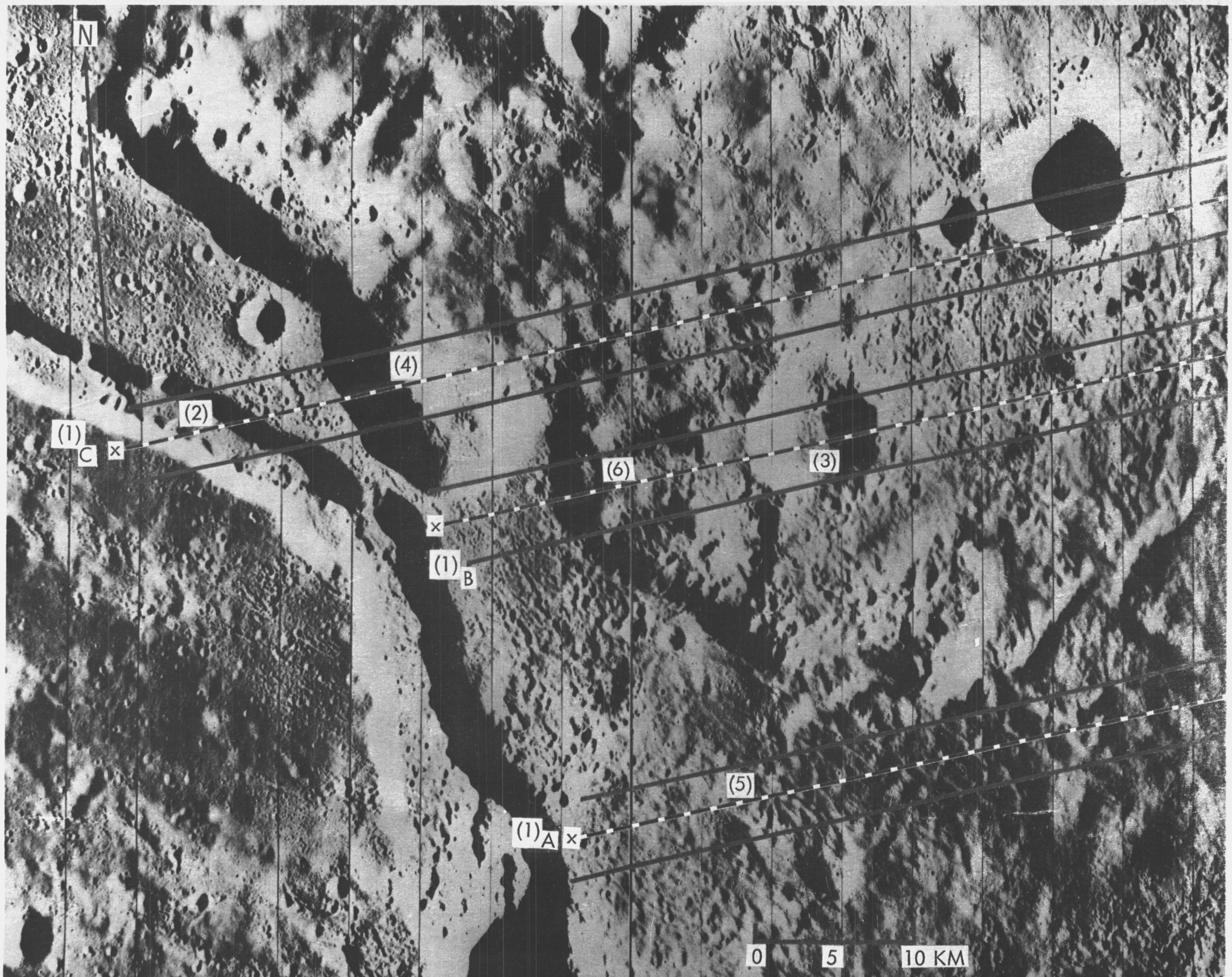
(4) RIDGE ≈ 1000 M HIGH.

(5) TERRAIN SLOPES UP SHARPLY.

(6) RIDGE ≈ 600 M HIGH.

SUN ANGLE ≈ 15°

FIGURE 9


N
(1) C
(2)
(4)
(6)
(3)
(1) B
(1) A
(5)
0
5
10 KM

L.O.V M.R 203.

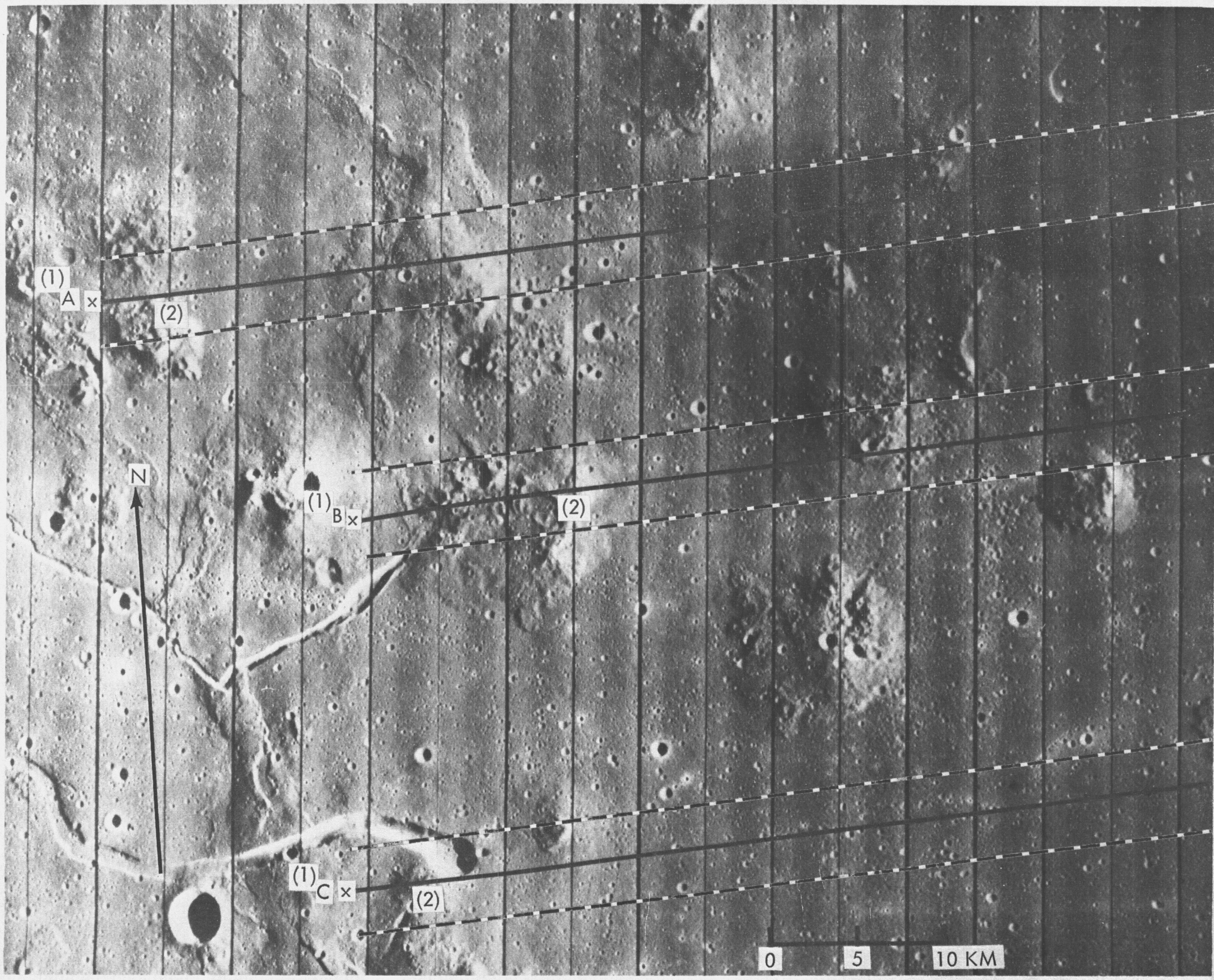
MARIUS HILLS

(1) a;b;c LANDING SITES IN ORDER OF PREFERENCE.

(2) STEEP VOLCANIC DOMES. (height ≃ 500)

SUN ANGLE ≃ 16°

FIGURE 10


(1) A ×
(2)
N
(1) B ×
(2)
(1) C ×
(2)
0
5
10 KM

APPENDIX

AZIMUTH OF APPROACH

The calculations below are subject to the following assumptions:

(1) librations are not considered, and

(2) there is no plane change at either landing or take-off.

Refer to Figure A-1.

In the primed system of coordinates (the x' y' plane contains the CSM orbit with inclination I), the velocity vector (of the CSM) is:

$$* \quad \overline{V}' = v(-\hat{i}' \sin\theta' + \hat{j}' \cos\theta' + k' \cdot 0)$$

in the umprimsed set of coordinates (x y plane is equatorial)

$$\frac{\overline{V}}{v} = -\hat{i} \sin\theta' + \hat{j} \cos\theta' \cos I + \hat{k} \cos\theta' \sin I$$

A unit tangent to any latitude line is

$$** \quad \overline{T} = -\hat{i} \sin\theta + \hat{j} \cos\theta + \hat{k} \cdot 0$$

---

* $\overline{V}'$ and $\overline{V}$ are the same vector but expressed in primed and unprimed coordinates respectively.

** θ' is measured in the CSM orbit plane from the line of nodes. θ is measured in the equatorial plane from the line of nodes.

The scalar product of $\frac{\overline{V}}{v} \cdot \overline{T}$ yields the cosine of γ, the angle between them

$$\cos\gamma = \sin\theta \sin\theta' + \cos\theta \cos\theta' \cos I$$

If we determine the relation between θ and θ', $\cos\gamma$ may be found.

Using the following relations:

$$x = x'$$

$$y' = y \cos I + z \sin I$$

$$\cos\theta' = \frac{x'}{\sqrt{x'^2 + y'^2}}$$

$$\sin\theta' = \sqrt{1 - \cos^2\theta'}$$

$$\frac{y}{x} = \tan\theta$$

$$\frac{z}{\sqrt{x^2 + y^2}} = \tan L \text{ (where L is the latitude)}$$

$$\frac{x}{\sqrt{x^2 + y^2}} = \cos\theta$$

$$\frac{y}{\sqrt{x^2 + y^2}} = \sin\theta$$

and

$$\sin\theta = \frac{\tan L}{\tan I} \text{ (defining a great circle)}$$

we obtain

$$\cos\gamma = \frac{\sin\theta}{\sqrt{1 + \frac{\cos^2 I}{\tan^2\theta}}} + \frac{\cos\theta \cos I}{\sqrt{1 + \frac{\tan^2\theta}{\cos^2 I}}}$$

Thus, the azimuth of approach (90° complement of γ) may be found if the inclination of the CSM orbit and θ are given. But θ and I are related to the latitude of the site and the staytime.

If ψ is the angle of rotation of the moon during the staytime, then:

$$\theta = \frac{\pi - \psi}{2}$$

And I may now be calculated by:

$$\sin\theta = \frac{\tan L}{\tan I}$$ where L is the latitude of the site.

γ is now determined.

TABLE 1

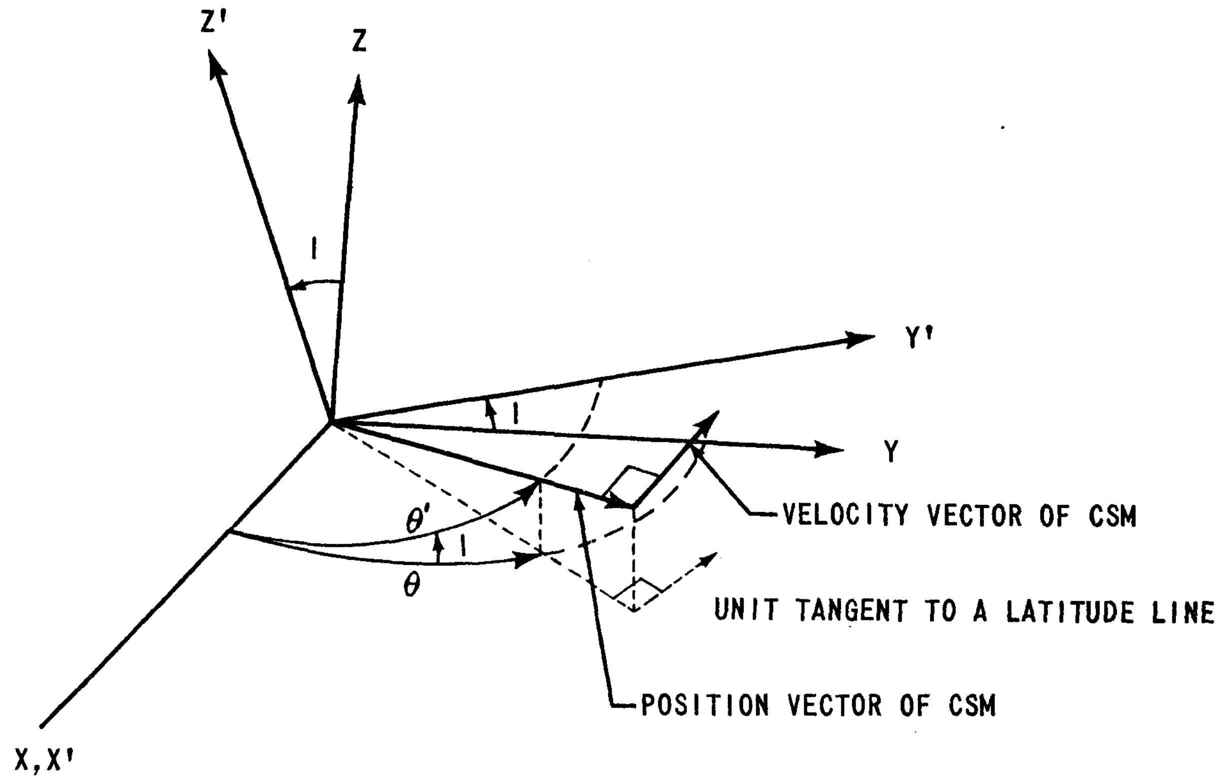
INCLINATION OF CSM ORBITS

Staytime \ Latitude	L = 10°	L = 20°	L = 30°	L = 40°	L = 50°
1 day	10.06°	20.11°	30.15°	40.17°	50.17°
2 days	10.25°	20.48°	30.62°	40.70°	50.70°
3 days	10.59°	21.11°	31.42°	41.60°	51.59°
4 days	11.09°	22.04°	32.60°	42.90°	52.85°

TABLE 2

γ

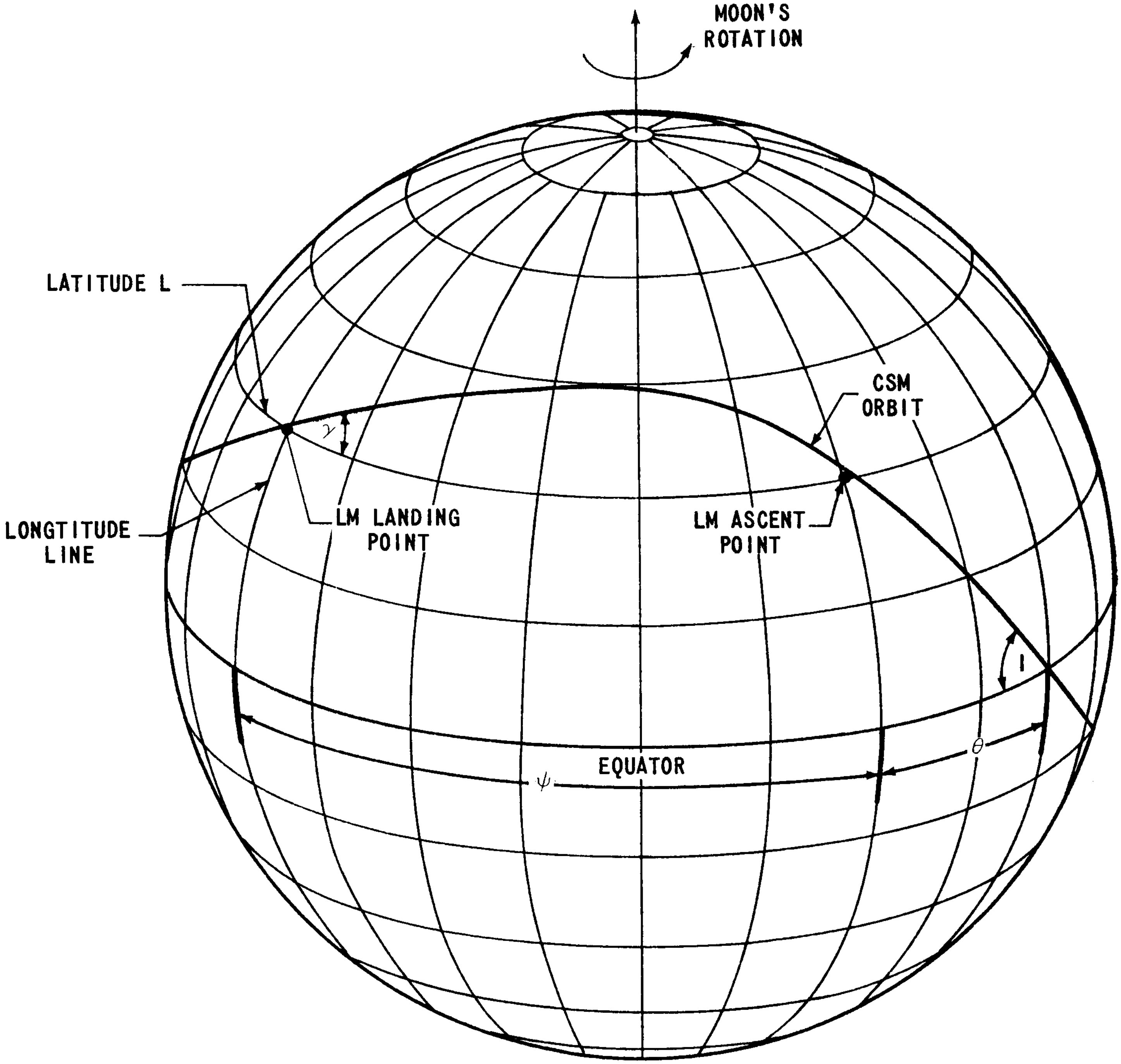
Staytime \ Latitude	L = 10°	L = 20°	L = 30°	L = 40°	L = 50°
1 day	1.12°	2.2°	3.2°	4.1°	4.89°
2 days	2.25°	4.4°	6.4°	8.28°	9.83°
3 days	3.44°	6.8°	9.8°	12.6°	14.9°
4 days	4.75°	9.3°	14.4°	17.04°	20.06°



θ = SELENOGRAPHIC LONGITUDE OF CSM FROM ASCENDING NODE

X,X' ARE ALONG THE LINE OF NODES.
PLANE X'Y' IS THE PLANE OF THE CSM ORBIT
PLANE XY IS THE PLANE OF THE LUNAR EQUATOR

FIGURE A-1



θ = ANGLE FROM ASCENDING NODE OF CSM ORBIT TO TAKE OFF POINT OF LM

$(90 - \gamma)$ = AZIMUTH OF APPROACH

ψ = ANGLE OF ROTATION OF MOON DURING STAY TIME

FIGURE A-2 - AZIMUTH OF APPROACH

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From: I. Silberstein

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